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ABSTRACT

Cognitive development proceeds through a series of four levels. The first is the single-class level, attained by infants at approximately 1 year of age. At the single-class level, concepts are based on element similarity or convention (for example, images and words for common objects). The second level is the relational level, attained by toddlers at about 2 years of age. At the relational level, concepts concern two classes and the relation between them. Relational concepts may be based on element similarity, convention, or relational similarity. The third level is the inferential level, attained by young children at about 5 years of age. At the inferential level, relational concepts are composed to form higher level concepts, and inferences are possible. Concepts at the inferential level may be based on element or relational similarity, convention, or internal consistency, the last of which gives semantic independence. The fourth level is that of logical reasoning, in which new expressions may be generated and the logical validity of inferences may be checked. Research indicates that this level is attained when children are about 11 or 12 years old. (Author/RH)

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A HIERARCHY OF CONCEPTS IN COGNITIVE DEVELOPMENT

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Abstract

It is proposed that cognitive development proceeds through a series of four levels. The first is the single class level (1C), attained at approximately one year, in which concepts are based on element similarity or convention. Images and words for common objects are examples. The second is the relational level (1R), attained at about two years, and where concepts include two classes and the relation between them. Concepts at this level may be based on element similarity, convention or relational similarity. The third is the inferential level (2), attained at about five years, where relational concepts are composed to form higher level concepts, and where inferences are possible. Concepts at this level may be based on element or relational similarity, convention or internal consistency, the last of which gives semantic independence. The fourth is the logical reasoning level (3), where new expressions may be generated and the logical validity of inferences may be checked. Research indicates that this level is attained at about 11-12 years.

It is proposed that the amount of information that children can utilize in a single decision, increases with age. Two experiments that illustrate this are shown in figure 1. Other experiments demonstrating the same point have been reported elsewhere (Halford, 1984).

It is further proposed that this limitation results in children passing through a sequence of four levels of thinking, which are defined in figure 2. Each level represents an equivalence class of concepts that all require the same amount of information to be considered in a single decision. The higher levels require more information to be considered than the lower levels, so the highest level which children can reach will be a function of age.

The lowest is the single class level, level 1C, where there is a symbol, such as a word or image, representing a single class of objects or events. An example would be words such as "dog" or "cup" which young children use for classes of objects or events. Sugarman (1982) has produced evidence that single classes in this sense are understood at one year of age. The only criteria of validity at this level are convention (as when a word is assigned to an object or event) or similarity (as when an image resembles an object or event). The only information needed to establish this assignment is the one symbol.

Next there is the relational level, level 1R. At this level a pair of symbols and the relation between them represent a pair of objects or events and the relation between them. This permits binary relations, such as the idea that a man is taller than a boy, to be cognized. According to Sugarman (1982) children can cognize two classes in this way at two years of age. Other types of concepts that can be cognized at this level are unary operators (e.g., that a particular action produces a particular result) and functional relations (e.g., the relation between wind and tree movement). These three types of concepts are structurally similar since all can be represented as sets of ordered pairs.

Criteria of validity at level 1R are element similarity and convention, as at level 1C, plus relational similarity. That is, the relation between two symbols may resemble the relation between two objects or events, even though the symbols do not resemble the objects or events. An example would be two sticks of different lengths representing two people of different size or age. Level 1R concepts require two symbols and the binary relation between them to be considered.

Next there is the inferential level, level 2. At this level two binary relations are composed into a single representation. The prototypical case would be transitivity, but other concepts such as hierarchical classification and multiple classification also belong to this level. These are

illustrated in figure 3. At this level all the criteria of validity at level 1R apply, plus the additional criterion of internal consistency. When two relations between symbols are assigned to two relations between objects or events, the assignment can be internally consistent or inconsistent. This is illustrated for arbitrary elements in figure 4. The top diagram is consistent because each element of the symbol system is assigned to one and only one element in the environment system, and vice versa. In the lower diagram the assignment is inconsistent and therefore invalid, because b is assigned to both * and ø, and # is assigned to both a and c. Such an inconsistency cannot arise at level 1, because any assignment of one relation must be consistent. The existence of the consistency criterion means that thought is freed from dependence on convention or similarity, which gives earlier thought the "iconic" quality noted by Bruner (1964).

Level 2 also confers the ability to draw inferences, because the composition of two relations permits a third to be generated. This also is illustrated in figure 3. However level 2 concepts require two binary relations to be considered, and are not mastered until 5 years of age (Halford & Wilson, 1980).

Level 2 is the earliest level at which transitive inference would be possible. Since transitivity of an asymmetric binary relation is the defining property of an ordered set, children who

cannot understand transitivity would not understand order (or seriation) either. A further consequence is that understanding of quantification would be restricted to the level of a nominal scale, or to understanding of single relations (such as more than, larger than). Since they do not understand quantification at the level of an ordinal scale, they would not be able to interpret an ambiguous, conserving transformation (Halford, 1982) and would not understand conservation (Siegler & Robinson, 1982). Evidence has been presented that transitivity and seriation are not understood until 5 years of age (Halford, 1984; Halford & Kelly, 1984). The same is true for multiple classification (Halford, 1980) and conservation (Halford & Boyle, 1985).

At level 3 compositions of binary operations, trivariate functions and ternary operations, can be represented. At this level new expressions can be generated, and this permits the logical validity of arguments to be assessed. Examples of level 3 reasoning are shown in table 2. By contrast, at level 2 inferences can be generated, but recognition of their validity must be based on empirical grounds. This can be illustrated with respect to figure 3. Imagine if the relations aRb and bRc represent the real-life relations "a is the uncle of b" and "b is the uncle of c" respectively. The closure of the diagram generates aRc, corresponding to the inference "a is the uncle of c", which is invalid

environmentally. However the representation meets the consistency criterion for level 2 thinking, in that each element at the symbol level is assigned to one and only one element at the environment level, and vice verse. Therefore internal consistency provides a criterion of valid representation at level 2, but does not distinguish valid and invalid inferences.

The criteria of validity at level 3 are the same as at level 2, but more information is required to be considered. Two binary operations must be considered, and since a binary operation is equivalent to a composition of two binary relations, the information required is greater than at level 2. Level 3 concepts are attainable at 11 years (Halford & Wilson, 1980).

Examples of concepts at each of the four levels are shown in table 2. Each concept is assigned to a level according to the minimum amount of information required to make the most complex single decision entailed in the concept. For example dimension-abstracted oddity is level 2 because it requires two binary relations, similarity and difference, to be considered to distinguish the odd object. Thus if we have three triangles, two of which are blue and one white, and one green square, the odd object is the square because it is different from the others in shape, which are all the same shape as each other. Both the relations of sameness and difference must be considered to recognize this. In simple oddity

however only one binary relation need be considered. Thus if we have two triangles and a square, we know the square is odd simply because it is different from the other two. Therefore simple oddity is level 1.

Table 2 illustrates the fact that the theory can treat a variety of concepts, coming from different research traditions, in the same framework. One of its functions therefore is to provide a basis for integrating cognitive developmental theory.

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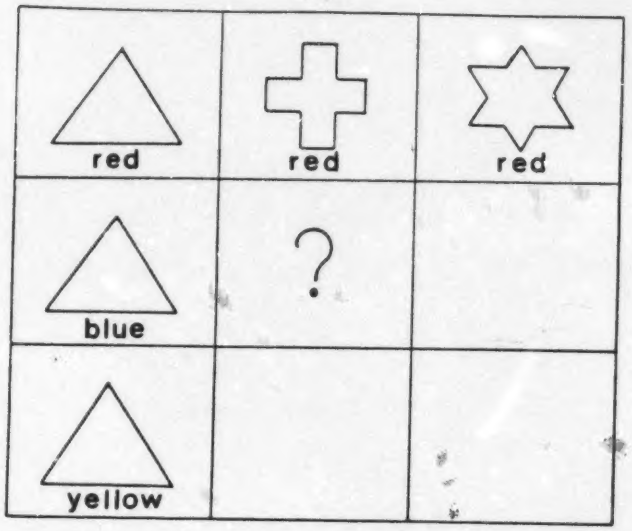
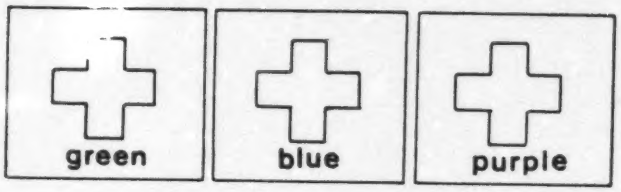
Figure 1. Two tasks that illustrate limitations to the information that children can utilize in a single decision. In the matrix task, children must choose one card from the three choice cards to fill the indicated square. At level 1 they need consider only one attribute, color in task A or shape in task B. At level 2 they must consider both shape and color. After learning set training, children below MA5 succeeded at level 1, but not at level 2, whereas children over MA5 succeeded at both levels. The inference is that younger children could not integrate two attributes in a single decision. In the mathematics task the missing operation(s) must be found. In the level 2 task, one operation (o) must be found. At level 3, two operations (o and *) must be found. Children below 11 years succeed at level 2, but not at level 3, whereas children over 11 succeed at both levels (Halford, 1978). Both operations must be considered in a single decision at level 3, because you cannot know you are right about one operation unless you know you are right about the other one too. Again the inference is that the younger children are limited in the information they can utilize in a single decision.

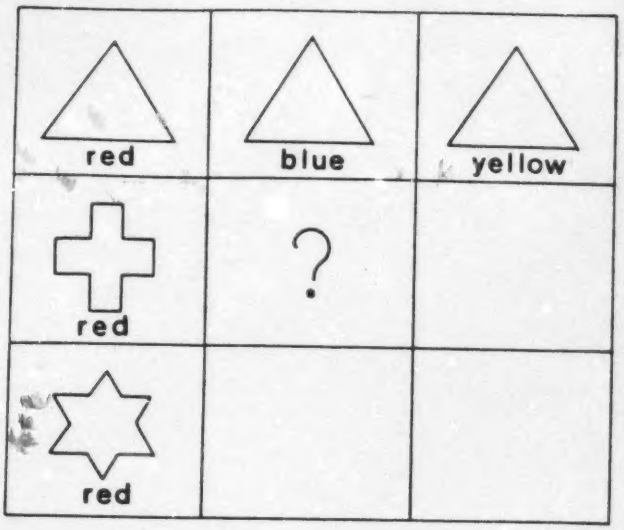
LEVEL 1

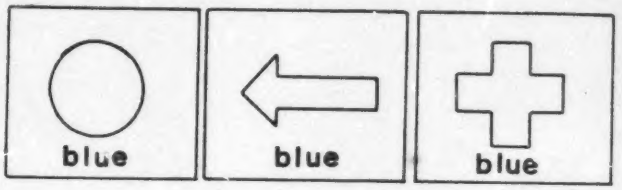
A



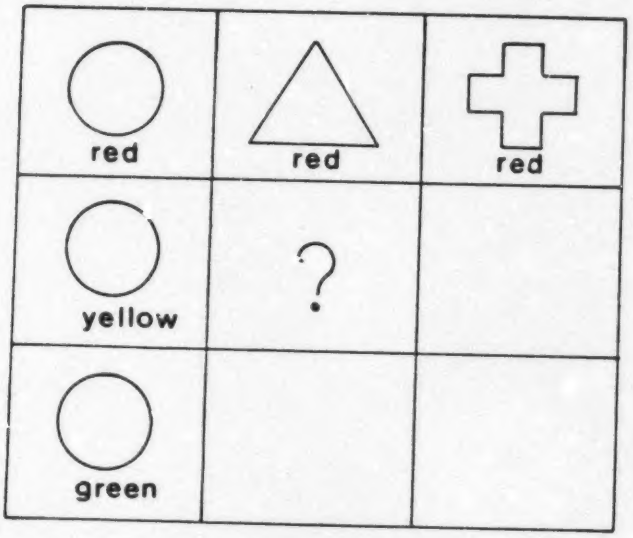


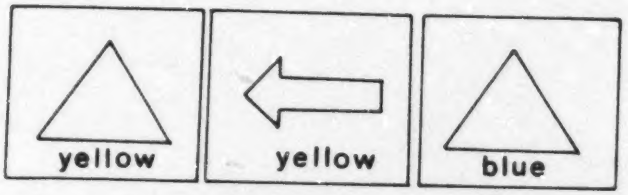
B





LEVEL 2





Mathematics problems at two levels: find the missing operation(s).

$(7 \cdot 3) \div 4 = 1$ level 2

$(7 \cdot 3) * 4 = 1$ level 3

Figure 2

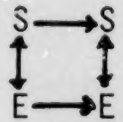
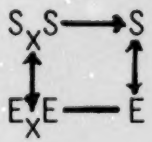
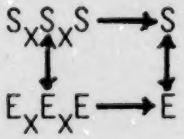
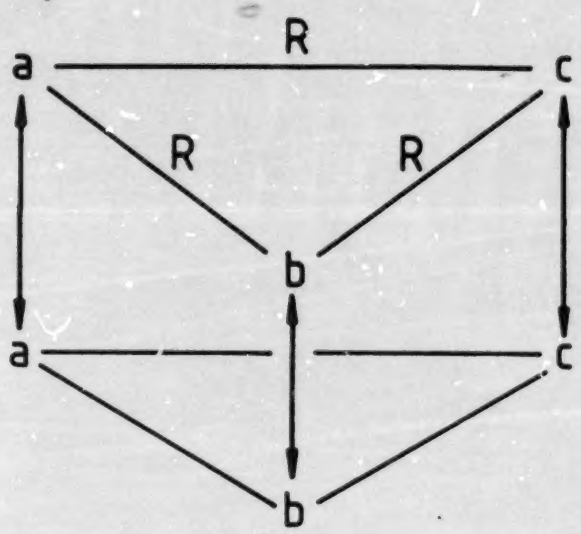
Cognitive System Level		Types of Concepts Represented	Information Processing Demands	Criteria of Validity	Age of attainment (years)
Single class thinking Level 1C		Single objects, classes and events.	One symbol to be considered	Convention, element similarity	1
Relational thinking Level 1R		Unary operators, binary relations, univariate functions	One binary relation to be considered	As for 1C, plus relational similarity	2
Inferential thinking Level 2		Binary operations, bivariate functions	Two binary relations to be considered	As for 1R, plus internal consistency	5
Logical reasoning Level 3		Ternary operations, compositions of binary operations, trivariate functions	Two binary operations to be considered	As for 2	11

Figure 3

Transitivity



symbol system

environment . system

Inclusion

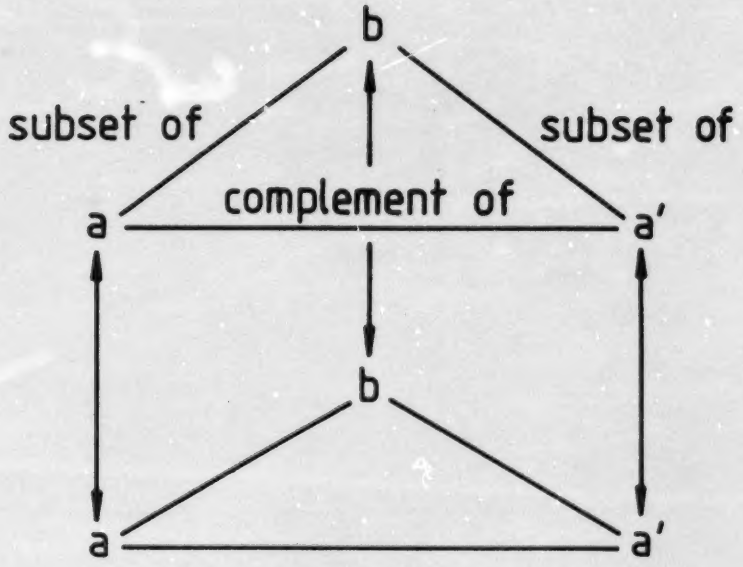
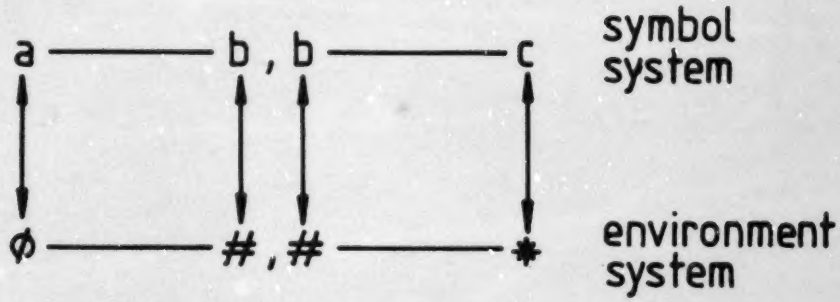


Figure 4

Level 2 consistent system



Level 2 inconsistent system

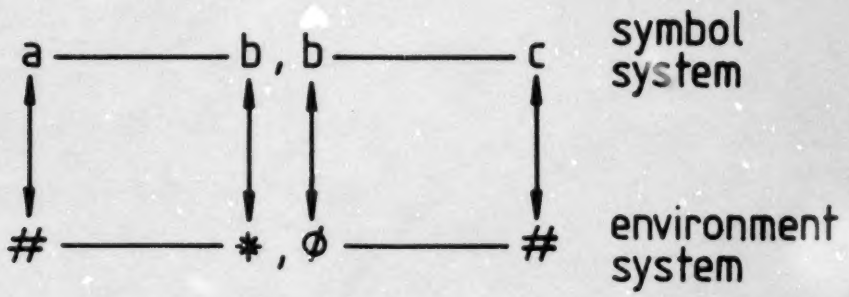


Table 1. Examples of Level 3 reasoning requiring two binary operations.

1. Mental generation of new expression by combining two operations

$(a + b) = x$; $(x \times c) = d$

(substituting)

$(a + b) \times c = d$

2. Checking the validity of an inference by operating on an expression

p implies q, p, therefore q

$((p \rightarrow q), p) \rightarrow q$

$(p \rightarrow q), p \equiv (\bar{p} \cup q) \cap p$

$\equiv (p \cap \bar{p}) \cup (p \cap q)$

$\equiv p \cap q$

since $p \cap q$ implies q, the deduction is valid.

TABLE 2: Examples of concepts belonging to each level

Level 1C: Single classes of objects and events.

Level 1R: Concepts which are equivalent to binary relations, univariate functions and unary operators.

Relations between objects, sets and classes

Functional relations (relations between action and outcome)

Unary operators

Single criterion classifications

Unidimensional pattern construction

Simple oddity

Level 2: Concepts which are equivalent to compositions of binary relations, binary operations and bivariate functions.

Dimension-abstracted oddity

Conditional discrimination

Transitivity and seriation

Inference

Dimension (such as quantity, size)

Conservation

Binary operations (e.g., arithmetic operations)

Hierarchical classification

Multiple (two dimensional) classification (e.g., matrix completion task)

Hypothesis testing in unidimensional concept attainment (dimension checking and more sophisticated strategies)

Hypothesis testing in attribute identification for conjunctive, disjunctive and conditional concepts

Two-dimensional pattern construction

Table 2 (cont'd)

Level 3: Concepts which are equivalent to compositions of binary operations, and trivariate functions.

Hypothesis testing in attribute identification for biconditional concepts

Hypothesis testing in rule identification for two-dimensional concepts (conjunction, disjunction, conditional, biconditional)

Concepts based on a composition of two binary operations (e.g., most of high school algebra is based on the rational number field, a system on which addition and multiplication are defined)

Recognizing validity of logical inferences